Influence of Dietary Macronutrient Composition in the Estimation of RMR Using Indirect Calorimetry

Sakiko Minagawa

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Project Advisor: Dr. Jackie Buell

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Abstract

Background: Endurance running leads to high exercise energy expenditure, and dietary energy intake should be adjusted to fuel this high-energy sport. Energy requirement can be predicted by Resting Metabolic Rate (RMR) and exercise energy expenditure. RMR is the estimated number of calories burned in 24 hours to maintain basic body function and balance, and can be measured using an indirect calorimeter. Prediction of energy needs is important to properly advise athletes for their athletic performance and health.

Objective: The purpose of this study is to investigate the inconclusive literature on the influence of dietary macronutrient composition (fat and carbohydrate) in the estimation of RMR using indirect calorimetry in adult female runners. RMR is often time estimated relying on assumptions, namely Respiratory Quotient (RQ), that may result in inaccurate RMR estimation in some populations, such as athletes, who have shown to have a variety of dietary macronutrient intake and nutritional status. The KORR Medical Technologies ReeVue indirect calorimeter used in this study predicts RMR with an RQ of 0.83, assuming adequate energy intake composed of a mixed diet. The statement of the problem examined in this study is as follows:

1. **What is the difference in ReeVue-estimated RMR compared with the Food Quotient-adjusted RMR?**
2. **Is RMR influenced by Calorie Consumption or Energy Availability?**

Methods: Data analyzed for this RMR comparison study was recorded as a follow-up study of 44 adult female recreational runners ages 24-62 (2009H0177). The parent study was designed to evaluate the characteristics of the female athlete triad (energy

availability, menstrual function, and bone mineral density). This follow-up study included a measure of RMR using the KORR Medical Technologies ReeVue. In analyzing the dietary data, macronutrient intake varied remarkably between subjects. In light of these findings, RMR was evaluated according to dietary intake. Dietary intake was evaluated using a Vioscreen Food Frequency Questionnaire (FFQ) and a self-reported three-day food record (3-FR). This data was then analyzed by ESHA Food Processor SQL diet analysis software. Energy Expenditure (EE) was estimated using the Bouchard physical activity record (B-PAR), and Resting Metabolic Rate (RMR) was estimated using the KORR Medical Technologies ReeVue indirect calorimeter. This machine estimates RMR from a measure of oxygen consumption. This oxygen consumption was combined with a Food Quotient (FQ) to determine the difference in RMR from the machine estimation.

Results:

This study revealed,

1. There is a statistically significant difference between RMR estimated by the ReeVue and the RMR adjusted by the FQ (Wilcoxon signed ranked test p= 0.000). However, 21kcal is not clinically significant.
2. There is no significant correlation between Calories or EA to RMR
    - Calories and RMR (Spearman's rho= -0.009, p=.955)
    - EA and RMR (Spearman's rho= -.112, p=.470)

Discussion/Conclusion: Although there is a statistically significant difference in RMR estimated by the ReeVue and RMR adjusted by the FQ, 21kcal is not clinically significant. The ReeVue can properly estimate RMR in subjects with varying dietary macronutrient content. Despite previous literature, there was no correlation between Calories consumed and EA to RMR, suggesting limitations of this study. It was observed that female runners on a high carbohydrate diet had a greater difference in RMR between the estimation by ReeVue and the adjustment by the FQ. This suggests that RMR estimated by the ReeVue should be considered for adjustment in female runners on a high carbohydrate diet. While the ReeVue with an assumed RQ of 0.83 to estimate RMR did not show clinically significant difference compared to the RMR adjusted by the FQ. In the future, crossover studies should be performed, determining different dietary protocols in the same subjects. RMR should be determined using a full metabolic cart, which measures both VCO_2 and VO_2.

Introduction

Some people run as a recreational and social activity, while some run competitively or even professionally. Running leads to high exercise energy expenditure, and dietary energy intake should be adjusted to fuel the energy demand of the sport correctly. Energy requirement can be predicted by Resting Metabolic Rate (RMR) and exercise energy expenditure. RMR is often estimated relying on assumptions, namely Respiratory Quotient (RQ), that may result in inaccurate RMR estimations in some populations, such as athletes, who have shown to have a variety of dietary macronutrient intake and nutritional status. Prediction of proper energy needs is important for athletes because of the consequences poor fueling can have on athletic performance and health. Nutritional inadequacy can lead to serious complications such as eating disorders, decreases in bone mineral density, injuries, reproductive complications, and nutritional deficiencies. Therefore, it is crucial that the assumptions made to estimate RMR are accurate in order to properly advise athletes on their individual energy needs.

RMR values are low with apparently low Energy Availability (EA) but also quite variable with macronutrient distribution. This observation lead to the core interests of this study; determine whether the macronutrient and energy content of the diet significantly influence ReeVue indirect calorimeter which estimates RMR with an assumed RQ, and whether this assumed RQ is a source of significant error in estimating RMR, and if so, should oxygen consumption be adjusted for macronutrient intake. The statement of problems examined is as follows:

1. **What is the difference in ReeVue-estimated RMR compared with the Food Quotient-adjusted RMR?**
2. **Is RMR influenced by Calorie Consumption or Energy Availability?**

Literature Review

Resting Metabolic Rate (RMR):

Resting Metabolic Rate (RMR) is the “sum of the metabolic processes of active cell mass related to the maintenance of normal body functions and regulatory balance during rest” (3) or simply, the number of Calories burned in 24 hours to maintain body function and balance. RMR can be measured and estimated in various ways. The most accurate method is through direct calorimeter, where the biologic heat released by an individual is measured in a closed system. However, direct calorimetry is very difficult to perform, can be very time consuming, and expensive. RMR can be easily estimated through common predictive equations. However studies have shown that commonly used RMR equations, such as Nelson, Mifflin St. Jeor, Owen, Schofield (weight), Schofield (weight and height), and Harris-Benedict, all overestimated RMR in healthy young women (17). RMR can also be estimated through an indirect calorimeter, which measures variables such as oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory quotient (RQ). Some indirect calorimeters only measure VO_2 with an assumed RQ to determine VCO_2. For an example, the MedGem Indirect Calorimeter calculates RMR with an assumed RQ of 0.85(1). The Korr Medical Technologies ReeVue Indirect Calorimeter calculates RMR with an assumed RQ of 0.83(2). Studies have shown positive results in using the ReeVue to assess RMR. The ReeVue indirect calorimeter has shown statistically similar RMR measurements compared to the Deltatrac, a commonly used machine used to measure RMR, which have been shown reliable in clinical settings (29, 30)

Respiratory Quotient (RQ):

RQ is the ratio of carbon dioxide production to oxygen consumption (VCO_2/VO_2), and is affected by fueling substrate used by the body (23). The complete oxidation of carbohydrate and fat is approximately 1.0 and 0.7 respectively (12, 34). The RQ of a protein is difficult to measure because the nitrogen of protein is eliminated in the urine and is not completely oxidized, however is estimated to be around 0.8 (34). RQ of a normal mixed diet is considered to be between 0.82 and 0.85 (32). RQ shifts depending on diet composition and energy availability. The RQ of a well-nourished person is approximately identical to the RQ of the individual's diet RQ (26). Underfeeding, defined as the intake of less than 90% of caloric requirement for the individual, encourages the use of fat stores, and causes a decrease in RQ in an average individual. In contrast, overfeeding, defined as nutritional intake of greater than 110% of the individual's caloric requirement, encourages lipogenesis, and predicts an increase in RQ (23).

	RQ
Carbohydrate	1.0
Fat	0.70
Protein	0.80
Mixed	0.82-0.85

Table 1: RQ values of different substrates (12, 32, 34)

Food Quotient (FQ):

Studies have shown mixed results in the relationship between RQ and FQ with varying dietary macronutrient composition. The FQ is the diet-adjusted RQ, in other words, the FQ represents the RQ based on the individual's diet composition. FQ is calculated as follows;

$$FQ = (1.00\times \text{ \%calories from carbohydrates}/100) + (0.70\times \text{ \%calories from lipids}/100) + (0.81\times \text{ \%calories from proteins}/100)$$

Hill *et al* examined the effects of diet composition and substrate utilization (15). The findings indicated that the macronutrient consumed (fat and carbohydrate) in the diet influences fat and carbohydrate oxidized by the body.

However, in another study performed by Goris *et al*, RQ did not have any significant relationship to FQ (14). Changing macronutrient composition did not affect the RQ. Only changes in body mass seemed to affect RQ. However, this study measured RQ representing a short period, and suggested measuring a 24-hour RQ for a better representation of habitual FQ.

Abbott et.al examined the effects of dietary fat and carbohydrate on energy expenditure(4), This study measured 24-hour energy expenditure using a whole body calorimeter eating a mixed, high-fat, and high carbohydrate diets. High fat diet consisted of 43% carbohydrate, 42% fat, and 15% protein. High carbohydrate diet consisted of 65% carbohydrate, 20% fat, and 15% protein. Results showed that the 24-hr RQ was significantly higher when on a high carbohydrate diet when compared to a high fat diet. 24-hour RQ was less then the respiratory quotient of the food (FQ) when on a high carb diet. Similarly, Westerterp suggested that those whose diets are higher in carbohydrate, leads to a greater difference between the FQ and RQ (42). The RQ value is lower than the FQ. This study suggests that substrate use is closer to intake for diets higher in fat compared to diets higher in carbohydrate.

Macronutrient Composition:

Recommendation on dietary macronutrient composition for adequate health is constructed for athletes. According to Institute of Medicine, the acceptable macronutrient distribution range for carbohydrate is 45-65% for carbohydrate, 10-35% for protein, and 20-35% of energy for fat (21). Although this recommendation is set, there is a wide range of dietary macronutrient intake consumed among athletes. The consumption of high percentage of carbohydrate days before an endurance event has been long known and recommended to increase glycogen storage to improve performance (6, 7). However, recent studies, led by Volek, have shown high fat, moderate-protein, and low-carbohydrate diet result in better performance among ultra-endurance athletes (27). Athletes may choose to alter their diets, whether it is high carbohydrate, or high fat diet, in desire to maximize performance and recovery.

Accuracy of Caloric Balance:

While an exact energy requirement for an individual is not easy to determine, prediction of proper energy needs is important for athletes because of the consequences poor fueling can have on athletic performance and health. Nutritional inadequacy can lead to serious complications such as eating disorders, decreases in bone mineral density, injuries, reproductive complications, and nutritional deficiencies. In order to determine nutritional adequacy, dietary intake/caloric input as well as energy expenditure/ caloric output must be estimated or measured.

Caloric Input: Dietary Intake

Determining dietary intake, or the number of calories consumed, is the first step in determining caloric balance. Studies show large caloric intake variability in female runners. For example, Marcus observed low daily caloric intake, ranging from 1272-1715kcals/day in female endurance runners using 3-day food records (22). On the other hand, Deuster found high caloric intake up to almost 2400 kcal/day in highly trained women runners, also using 3-day food records (9). Appropriate dietary intake assessment methods to support this wide variability of caloric intake in female runners must be established. 3-day food records (3-FR) and Food Frequency Questionnaires (FFQ) are two of many dietary assessment methods to determine dietary intake. 3-FR method requires recording of the quantity/serving size of every food or drink consumed of 3 days, typically 2 days during the week and one day on the weekend, that most closely resembles their typical dietary intake (28). 3-FR are often times entered into computerized analysis software to evaluate detailed nutritional information such as total Calories, and nutrient values such as carbohydrate, protein, and fat (28). FFQ, specifically the Vioscreen FFQ, has been assessed and shown to have a reasonable validity, and a reliable diet analysis method when compared to 3-FR method (16). FFQ has an advantage over 3-FR, as it evaluates long-term diet intake rather than generalizing dietary intake from 3 days of food records. However, underreporting is an issue often seen in these methods (11, 35). Scagliusi evaluated 3 dietary assessment methods including the FFQ and 3-FR. Out of the 65 women aged 18-57, 42 women, or approximately 65%, were categorized as under-reporters (35). Although underreporting is an issue, studies frequently use these methods because of its lower cost and relative ease to administer (44). Oakley evaluated Caloric intake of female runners using 3-FR analyzed by the ESHA food processor and the Vioscreen FFQ (28). Although ESHA consistently produced higher caloric values than the Vioscreen FFQ, this difference was not significant (28).

Caloric Output: Energy Expenditure

Energy Expenditure (EE) varies depending on the frequency, intensity, time, and type of exercise. Female runner who runs 5 miles/week will burn more energy than a female runner who runs 30 miles/week. The Doubly Labeled Water (DLW) method is considered the gold standard to determine EE (24). This method has ben validated in numerous studies including elite female athletes (37, 38, 41). The procedure includes consuming doses of H2O18, where the isotopes H2 and O18 are ultimately eliminated from the body as CO2 and H2O. Urine samples are collected to determine the ratio of the isotopes eliminated, to calculate CO2 production. Total EE is then calculated using the CO2 production rate that was determined using the DLW, and combining it with the RMR determined by indirect calorimetry (36). Although the DLW method is considered the gold standard in determining EE, this method is hard, expensive, and very time consuming to perform, and is not often used.

Self-reported physical activity record, such as the Bouchard Physical Activity Record (BPAR) is another way to determine EE. Precision from self-report may be a concern due to recall and memory bias especially in children and individuals with cognitive dysfunction (31, 39, 40). However, studies often use the BPAR, as an alternative to the DLW method, as this method is less expensive and much easier to carry out. BPAR is a 3-day activity record, where every 15minute period was recorded on a scale of 1-9, where 1 is sedentary activity, and 9 is high intensity activity, which corresponds to 1.0 MET to 7.8 METs respectively(5). The participants recorded the same 3 days which food intake was also recorded. Out of the 3 days, one day had to be a Saturday or Sunday. BPAR has been validated by the Tritrac-R3D accelerometer and has been used in numerous studies to assess EE including children and adolescent, as well as in distance runners (5, 10, 39, 43).

Energy Availability:

Once dietary energy intake and EE is determined, Energy Availability (EA) can be calculated. EA is the energy that remains after subtracting out exercise energy expenditure from dietary energy intake, controlled for Lean Body Mass (LBM) (19).

EA= (Dietary energy intake- Exercise energy expenditure)/ kg LBM.

Therefore, energy availability is the energy that remains to be used for the body's physiological system after accounting for exercise. EA can be estimated by determining energy intake, recording ones diet and using a diet analysis software, determining EE, using a heart rate monitor during exercise, and finally determining LBM using a bioelectrical impendence body composition scale (19). Studies recommend EA between 30-45kcal/kg of LBM per day for athletes who are trying to lose weight, and EA greater than 45kcal/kg of LBM per day for optimal health and performance in endurance athletes (8, 19). Prevalence of low EA has been observed in marathon runners as well as female collegiate track athletes (8, 20). Low EA (<30 kcal/kf LBM) can be caused by low dietary intake, excessive exercise expenditure, or the combination of both. Exercising women with low EA may result in menstrual dysfunction and lowered RMR as a body's protective way of preserving long-term energy deficiency (13, 18, 25, 33). The cycle of low EA results in lowered RMR, therefore the athlete will have to reduce EA furthermore to see weight loss, causing once again a decrease in RMR. This vicious cycle can have detrimental effects in female athletes.

Purpose of Study

There is ample evidence that humans adapt to energy restriction by reducing RMR. However, literature is inconclusive concerning the relationship between macronutrient content (fat and carbohydrate) in the estimation of RMR in female runners. As stated earlier, the ReeVue predicts RMR with an assumed RQ of 0.83. This RQ value is based on the assumption of adequate caloric intake composed of a mixed diet. Based on previous literature, we hypothesized that subjects eating a mixed diet will have a FQ close to RQ; therefore ReeVue RMR should be similar to the RMR calculated by the FQ. Subjects with a high carbohydrate diet will have a FQ greater than 0.83, therefore they will have a greater FQ estimated RMR and subjects with a high fat diet will have a lower RQ than 0.83, therefore they will have a lower FQ estimated RMR. However, high variability of dietary macronutrient composition intake for optimal performance in endurance athletes has been reported. Determining proper RMR values for athletes who do not consume a typical mixed diet needs to be examined and adjusted if necessary to accurately advise these athletes in regards to their performance and health.

Methods

Subjects:

The data analyzed for this study was a follow-up study of 44 adult female recreational runners ages 24-62 (2009H0177). All 125 original participants were 18 years of age or older, and had run at least 15 miles per week during the last 6 weeks of data collection. Participants had no known bone density or thyroid issues, nor were they on medications that may have influenced bone mass. The participants in the follow-up study had similar requirements, however, did not have a minimum running requirement.

Height and Weight:

Subject’s height and weight was determined using a Health-O-Meter stadiometer and scale (Model 500KL).

Body Composition:

Body composition was recorded by the General Electric Lunar iDXA Encore 14.0. The iDXA estimates the subject’s bone mass and body composition (lean and fat mass).

Dietary Energy Intake:

A three-day food log analyzed using ESHA Food Processor SQL and Vioscreen Food Frequency Questionnaire (FFQ) were two nutrition tools used to examine the female runners’ diets. ESHA Food Processor is a research database of more than 55,000 foods and recipes. ESHA analyzes for 163 nutritional components. These nutritional components include calories, calories from fat, saturated fat, trans fat, protein, and carbohydrates, as well as specific vitamins, minerals, saturated fat, amino acids, and sugars. Vioscreen, dietary analysis software, consists of dietary questionnaires that assess nutritional habits of the past 90 days. It takes approximately 20 minutes to complete. The questionnaire examines subject’s dietary behavior and estimates dietary intake and provides dietary analysis. In hopes of obtaining an estimated nutritional value as close to their actual food consumption, the average macronutrient values (carbohydrate, protein, and fat) determined by ESHA and Vioscreen were used to investigate the statements of problem.

Exercise Energy Expenditure:

Exercise Energy Expenditure was estimated using the Bouchard Physical Activity Record (BPAR). BPAR is a 3-day activity record, where every 15-minute period was recorded on a scale of 1-9 corresponding to 1.0 MET to 7.8 METs respectively. The participants recorded the same 3 days which food intake was also recorded. Out of the 3 days, one day had to be a Saturday or Sunday. Energy Expenditure ratings greater or equal to 6 were used for calculations of exercise energy expenditure. *See Appendix A

Energy Availability:

Energy Availability (EA) was calculated as (Dietary energy intake- Exercise energy expenditure)/ kg LBM. Dietary energy intake was determined by the average dietary macronutrient intake estimated by the ESHA food processor and Vioscreen. Exercise Energy Expenditure was determined using the BPAR, and finally LBM was determined by the iDXA scan. EA below 30kcal/kg of LBM/day was determined as low

EA, and EA between 30-45kcal/kg of LBM/day was determined as adequate, and EA greater than 45kcal/kg of LBM/day to be optimal to support the subject's running performance and health.

Resting Metabolic Rate:

ReeVue is an indirect calorimeter that uses a mixing chamber to measure energy utilization. ReeVue directly measures the concentration of oxygen exhaled though a simple mouthpiece. The mixing chamber collects all the exhaled gas to measure the precise oxygen exhaled (in percent). As there is a direct correlation of 4.813 calories burned for every milliliters of oxygen consumed, ReeVue can then calculate RMR. RMR was determined by the KORR Medical Technologies ReeVue indirect calorimeter. The ReeVue machine measures a subject's VO_2, and estimates RMR using the abbreviated weir equation with an assumed RQ of 0.83. After the ReeVue is turned on, it will automatically calibrate and will beep to indicate that calibration is complete and ready to be used. The ReeVue is very simple, as it is self-calibrating and measures barometric pressure, temperature, and humidity on its own. The ReeVue requires no training or certification, nor does it require a computer or software. Pre-test requirements for the subjects included, 1. Fast for at least 4 hours before the test, 2. Avoid exercising, and 3. Avoid stimulants such as caffeine. Each subject was asked to sit in a chair and relax. A disposable mouthpiece comprised of a one-way valve, connected to the ReeVue machine, was positioned with the subject where they were asked to keep lips sealed around the mouthpiece and breath normally through it. The one-way valve insured that only the expired gas entered the machine. A nose clip was also given to the subject to ensure that no air leaked through the nostrils and that all gas exchange occurred through the mouth. Each test lasts approximately 10 minutes, where the ReeVue machine will beep, indicating that the test is complete. Subject gender, age, height, and weight were entered into the machine and the data printed from measures. The RMR data were then entered into an excel spread sheet by subject number.

Food Quotient:

The FQ is the diet-adjusted RQ, and was calculated as follows;

$$FQ = (1.00\times \%\text{calories from carbohydrates}/100) + (0.70\times \%\text{calories from lipids}/100) + (0.81\times \%\text{calories from proteins}/100)$$

The % Calories of each macronutrient were obtained by the average macronutrient content from ESHA and Vioscreen. Since $RQ= FQ= VCO_2/VO_2$, the FQ value calculated from the equation was multiplied with the VO_2 measured by the ReeVue to determine assumed VCO_2.

FQ adjusted RMR:

The assumed VCO_2 from the FQ, and VO_2 measured by the ReeVue, was inserted in the Abbreviated Weir equation to determine the FQ adjusted RMR. The Abbreviated Weir Equation used to determine RMR was;

$$RMR= [(3.94 \times VO_2) +(1.1 \times VCO_2)]\ 1.44$$

The FQ adjusted RMR (kcal/kg) was multiplied by the subject's weight in kg to obtain their relative RMR (kcal)

Difference in RMR (diffRMR):

The difference in RMR was calculated by subtracting the ReeVue estimated RMR by the FQ adjusted RMR.

Statistical Analysis:

The sample size (N=44) drove us to use non-parametric Wilcoxon signed ranked test and Spearman's Correlation test. Wilcoxon Signed Ranked Test was used to determine significance of the difference between ReeVue-estimated RMR and the Food Quotient-adjusted RMR. Spearman's Correlation test was used to determine the significance of the correlation between Calories and EA to RMR. Significance was set a-priori at $p<0.05$.

Example Calculations

Subject Number Habitual diet	Equation	Subject 19 Mixed	Subject 13 High carb	Subject 62 High fat
1. ReeVue RMR (kcal)		1570	1368	850
2. Average Carbohydrate (g)	=(ESHA_Carb + Vioscreen_Carb)/2	200.6	228.1	186.0
3. Average Protein (g)	=(ESHA_Pro + Vioscreen_Pro)/2	77.5	81.7	83.5
4. Average Fat (g)	=(ESHA_Fat + Vioscreen_Fat)/2	76.0	68.8	90.9
5. Calories (kcal) (Energy Intake (EI))	=(AvgCarbx4)+ (AvgProx4) + (AvgFatx9)	1796	1858	1896
6. % Calories from Carbohydrate	=(AvgCarb/ EI) x100%	44.7	49.1	39.2
7. % Calories from Fat	=(AvgFat/ EI) x100%	38.1	33.3	43.1
8. % Calories from Protein	=(AvgProtein/ EI) x100%	17.2	17.6	17.6
9. Food Quotient (FQ)	=(1.00×%Cals from carbs/100) + (0.70×%Cals from fats/100) + (0.81×%Cals from proteins/100)	0.853	0.867	0.837
10. VO_2 measured by ReeVue (mL/kg/min)		3.54	4.06	2.16
11. FQ adjusted VCO_2 (mL/kg/min)	$VCO_2 = FQ \times VO_2$	3.02	3.52	1.90
12. FQ RMR using Weir Equation (kcal/ kg)	=[(3.94 x VO_2) +(1.1 x VCO_2)] 1.44	24.7	28.4	15.0
13. Weight (kg)		63.5	49.5	56.2
14. FQ RMR (kcal)	=Weir RMR x kg	1565	1404	842
15. Difference in RMR (kcal)	=(ReeVue RMR - FQ RMR)	4.8	-36.1	7.9
16. Lean Body Mass (kg) (LBM)		46.4	37.0	44.1
17. Energy Expenditure (EE)	=Avg Cals for 3 days of activity of 6 and up	374.3	275.0	556.7
18. Energy Balance (kcal/kg (EA)	=(Energy Intake- Energy Expenditure) /LBM	30.6	42.8	30.3

Table 2: Example Calculations of RMR and Energy Availability in High Fat, High Carb, and Mixed Diet

Results

Subjects:

Out of the 118 subjects from the parent study, 44 participated in the repeat study. While the initial study required running a minimum of 15 miles per week for the past 6 weeks, the women in this repeat study did not have a minimum running requirement. Demographic information of the participants in this repeat study, describing age, height, weight, and running mileage is described in table 1 (28).

Demographics Mean (± Std. Dev.) Min - Max	
Age (years)	40.8 (±9.1) 24 - 62
Height (in.)	64.6 (±2.77) 57.5 - 71.3
Weight (lbs.)	134.8 (±21.5) 97.2 - 203.6
Mileage (miles)	16.1 (±10.2) 0 - 40

Table 3: Demographics

This study had a limited number of participants with adequate EA; EA= [(Energy intake- Energy expenditure)/(Lean Body Mass)]. Table 2 summarizes Energy Availability distribution of the subjects. 29 out of the 44 subjects were categorized as Low Energy Availability (LEA) and 9 were considered adequate (30-45kcal/kg LBM), and 6 were optimal (> 45kcal/kg LBM) (28).

Energy Availability (kcal/kg LBM)	Number of Subjects
Low Energy Availability (LEA) <30	29
Adequate Energy Availability 30-45	9
Optimal Energy Availability >45	6

Table 4: Energy Availability Distribution

Statement of Problem 1:

1. What is the difference in ReeVue-estimated RMR compared with the Food Quotient-adjusted RMR?

There is a statistically significant difference between RMR estimated by the ReeVue and the RMR adjusted by the FQ (Wilcoxon signed ranked test p= 0.000). The RMR determined by the FQ estimated approximately 21 kcal greater than the RMR measured by the ReeVue. Although statistically significant, 21 kcal is not clinically significant.

	Mean (±Std Dev)	Minimum	Maximum
ReeVue RMR	1395.2 (±249.6)	792.0	2045.0
Food Quotient RMR	1416.5 (±252.0)	804.3	2044.9
Difference in RMR (ReeVue- FQ)	-21.335 (±19.6)	-92.0	7.9
Average Macronutrient Calories	1770.7 (±486.6)	820.6	3017.9

Table 5: Simple Statistics of RMR, Difference in RMR, and Average Macronutrient Calories

Statement of Problem 2:

2. Is RMR influenced by Calories or Energy Availability?

There was **no significant correlation** between Calories consumed or EA and RMR. Correlation between Calories and RMR and correlation between EA and RMR were Spearman's rho= -0.009, -.112, and p=.955, .470 respectively.

		Energy Availability	**Calories**
RMR	Spearman's Rho	-.112	-.009
	p	.470	.955
	n	44	44

Table 6: Nonparametric Spearman's correlations for Calories and Energy Availability to RMR

Discussion

Based on this female runner study, there is a significant difference between the RMR values determined by the ReeVue indirect calorimeter to the Food Quotient (Wilcoxon signed ranked test; p= 0.000). However, 21 kcal is not clinically significant. 21 kcal is approximately, 1/3 of a banana, or 1/4th cup of fat-free milk, or 3 raw almonds. Even though the ReeVue consistently estimated 21 kcal less than the FQ, this difference is not clinically significant to propose an alternative method to determine RMR in subjects consuming a non-mixed diet. As mentioned before, the ReeVue indirect calorimeter is very simple and easy to use, therefore if ReeVue is an option available for use, this study shows that the ReeVue is sufficient in estimating RMR compared to the FQ for individuals despite varying macronutrient composition.

Similar to the results seen by Westerterp, the results in this study also showed a trend in subjects consuming a high carbohydrate diet having greater RQ compared to that of the high fat or mixed diet (42). A RQ greater than 0.83 will calculate a higher RMR value compared to the RMR determined by the ReeVue machine with an assumed RQ of 0.83. Interestingly, the subject with the closest FQ value to 0.83 was on a high fat diet, not a mixed diet.

However, unlike previous literature, no significant correlation was determined between Calories consumed and RMR (Spearman's rho= -0.009, p=. 955) nor EA and RMR (Spearman's rho= -.112, and p=. 470). Several factors including age, reporting and recording of dietary intake and physical activity may have been a source of this uncommon result.

Limitations

Several limitations were observed in this study. FQ is hard to accurately determine due to the difficulty in recording and reporting food intake. When dietary information is collected, participants may underestimate food consumption. Although the difference in nutritional data obtained from the participants through the ESHA and Vioscreen were not significant, Oakley states that the ESHA repeatedly reported values higher than the Vioscreen (28). This suggests that a better method of obtaining dietary information is needed. Also, poor dietary intake description such as “popcorn” may have distorted the data. Popcorn could mean air-popped plain popcorn or buttered popcorn, which will have significantly different fat contents.

Another limitation of this study was the assumption that the participants maintained similar dietary composition, to the dietary intake recorded to be analyzed, the day prior to the ReeVue measurement. Eating different food composition compared to the recorded food intake may skew the RMR value and results obtained from this study.

As mentioned before many factors affect RMR values such as gender, age, FFM, etc. Previous study suggests that exercise can slow down the reduction in RMR with a decreased energy intake. Since this follow-up study did not have a minimum running requirement exercise could not be controlled. Another factor, energy availability has also been shown in previous literature to have an affect in RMR. Most of the participants in this study reported low energy availability; therefore conclusions made in this study by these subjects are not controlled for adequate energy intake.

In future research, crossover studies with different dietary macronutrient composition (high fat, high carbohydrate) protocols in the same subject should be performed. It should be noted that in this study, the significance in RMR values was determined compared to the diet-adjust food quotient. However, the food quotient equation is still an estimate and does not give a true RQ, therefore an RMR value. To further investigate the appropriateness of the RMR value determined by the ReeVue machine with a varying diet composition (RQ not equal 0.83), participants' RQ should be calculated using a full metabolic cart observing VCO_2 and VO_2. This way, RQ assumptions do not have to be made and can be directly measured reflecting upon dietary composition.

Conclusion

Endurance running leads to high exercise energy expenditure, and dietary energy intake should be adjusted to fuel this high-energy sport. Therefore prediction of energy needs is important for athletes because of the consequences poor fueling can have on athletic performance and health. Nutritional inadequacy can lead to serious complications such as eating disorders, decreases in bone mineral density, injuries, reproductive complications, and nutrient deficiencies. Accuracy of the assumptions made to estimate Resting Metabolic Rate (RMR) to properly advise athletes on their individual energy needs is crucial. Although the ReeVue indirect calorimeter estimates RMR with an assumed RQ of 0.83, it is an appropriate tool to use in athletes consuming varying dietary macronutrient composition.

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References

1. Microlife Medical Homes Solutions MedGem: Overview [Internet] [cited 2015 March/17]. Available from: http://www.mimhs.com/medgem/solutions/intermediate0/med/overview/.

2. ReeVue Medical RMR Metabolic Rate Analysis System [Internet] [cited 2015 March/2016]. Available from: http://korr.com/products/medical-metabolic-rate-analysis-system/.

3. Energy Expenditure (EE): Glossary (2005) [Internet]: Academy of Nutrition and Dietetics [cited 2016 March, 14]. Available from: https://www.andeal.org/topic.cfm?menu=5299&cat=1520.

4. Abbott WG, Howard BV, Ruotolo G,Ravussin E,. Energy expenditure in humans: effects of dietary fat and carbohydrate. *Am J Physiol*. 1990; 258(2):347-51.

5. Bouchard C, Tremblay A, Leblanc C, Lortie G, Savard R,Thériault G,. A method to assess energy expenditure in children and adults. *Am J Clin Nutr*. 1983; 37(3):461-7.

6. Burke LM, Hawley JA, Wong SH,Jeukendrup AE,. Carbohydrates for training and competition. *J Sports Sci*. 2011; 29:17-27.

7. Costill DL. Carbohydrates for Exercise: Dietary Demands for Optimal Performance. *Int J Sports Med*. 1988; 9(1):1-18.

8. Day, J., Wengreen, H.,Brown, K.,. Prevalence of Low Energy Availability in Female Collegiate Athletes. *Journal of the Academy of Nutrition and Dietetics Journal of the Academy of Nutrition and Dietetics*. 2014; 114(9):A92.

9. Deuster PA, Kyle SB, Moser PB, Vigersky RA, Singh A,Schoomaker EB,. Nutritional survey of highly trained women runners. *Am J Clin Nutr*. 1986; 44(6):954-62.

10. Eisenmann JC WE. Estimated energy expenditure and physical activity patterns of adolescent distance runners. *Int J Sport Nutr Exerc Metab*. 2007; 17(2):178-88.

11. Ferriolli E, Pfrimer K, Moriguti JC, Lima NK, Moriguti EK, Formighieri PF, Scagliusi FB,Marchini JS,. Under-reporting of food intake is frequent among Brazilian free-living older persons: a doubly labelled water study. *Rapid communications in mass spectrometry : RCM*. 2010; 24(5):506-10.

12. Flatt JP,. Body composition, respiratory quotient, and weight maintenance. *Am J Clin Nutr*. 1995; 62(5).

13. Gibbs JC, Williams NI, Mallinson RJ, Reed JL, Rickard AD,De Souza MJ,. Effect of high dietary restraint on energy availability and menstrual status. *Med Sci Sports Exerc*. 2013; 45(9):1790-7.

14. Goris AHC WK. Postabsorptive respiratory quotient and food quotient-an analysis in lean and obese men and women. *Eur J Clin Nutr*. 2000; 54(7):546-50.

15. Hill, James O., Peters, John C., Reed, George W., Schlundt, David G., Sharp, Teresa, Greene,Harry L.,. Nutrient balance in humans: effects of diet composition. *Am J Clin Nutr*. 1991; 54(1).

16. Labonté MÈ, Cyr A, Baril-Gravel L, Royer MM,Lamarche B,. Validity and reproducibility of a web-based, self-administered food frequency questionnaire. *Eur J Clin Nutr*. 2012; 66(2):166-73.

17. Li AC, Tereszkowski CM, Edwards AM, Simpson JA,Buchholz AC,. Published predictive equations overestimate measured resting metabolic rate in young, healthy females. *J Am Coll Nutr*. 2010; 29(3):222-7.

18. Loucks AB TJ. Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. *J Clin Endocrinol Metab*. 2003; 88(1):297-311.

19. Loucks, Anne B., Kiens, Bente, Wright,Hattie H.,. Energy availability in athletes. *Journal of Sports Sciences Journal of Sports Sciences*. 2011; 29(sup1):S7-S15.

20. Loucks A. Low Energy Availability in the Marathon and Other Endurance Sports. *Sports Medicine*. 2007; 37(4):348-52.

21. Manore MM. Exercise and the institute of medicine recommendations for nutrition. *Curr Sports Med Rep Current Sports Medicine Reports*. 2005; 4(4):193-8.

22. Marcus R, Cann C, Madvig P, Minkoff J, Goddard M, Bayer M, Martin M, Gaudiani L, Haskell W,Genant H,. Menstrual function and bone mass in elite women distance runners. Endocrine and metabolic features. *Ann Intern Med*. 1985; 102(2):158-63.

23. McClave SA, Lowen CC, Kleber MJ, McConnell JW, Jung LY,Goldsmith LJ,. Clinical use of the respiratory quotient obtained from indirect calorimetry. *JPEN.Journal of parenteral and enteral nutrition*. 2003; 27(1).

24. Melanson EL Jr FP. Physical activity assessment: a review of methods. *Crit Rev Food Sci Nutr*. 1996; 36(5):385-96.

25. Melin, A., Tornberg, Å. B, Skouby, S., Møller, S. S., Sundgot-Borgen, J., Faber, J., Sidelmann, J. J., Aziz, M.,Sjödin, A.,. Energy availability and the female athlete triad in elite endurance athletes. *SMS Scandinavian Journal of Medicine & Science in Sports*. 2015; 25(5):610-22.

26. Miles-Chan JL, Dulloo AG,Schutz Y,. Fasting substrate oxidation at rest assessed by indirect calorimetry: is prior dietary macronutrient level and composition a confounder? *International journal of obesity (2005)*. 2015; 39(7):1114-7.

27. Noakes, T., Volek, J. S., Phinney,S.D.,. Low-carbohydrate diets for athletes: what evidence? *British Journal of Sports Medicine British Journal of Sports Medicine*. 2014; 48(14):1077-8.

28. Follow up to recreational female runner study: further analysis of diet and energy availability [Internet].

29. Orr J. *EVALUATION OF A NOVEL RESTING METABOLIC RATE MEASUREMENT SYSTEM*. Salt Lake City, Utah. Available From: University of Utah, Department of Anesthesiology.

30. Phang PT, Rich T,Ronco J,. A validation and comparison study of two metabolic monitors. *JPEN.Journal of parenteral and enteral nutrition*. 1990; 14(3).

31. Rachele JN, McPhail SM, Washington TL,Cuddihy TF,. Practical physical activity measurement in youth: a review of contemporary approaches. *World journal of pediatrics : WJP*. 2012; 8(3):207-16.

32. Raju S, Nageshwara J. General Biochemistry and Nutrition. In: *Jaypee's Review of Medical Biochemistry: In Questions and Answers Format*. First Edition ed. New Delhi: Jaypee Bros.; 2005, p. 59.

33. Redman, Leanne M., Heilbronn, Leonie K., Martin, Corby K., de Jonge, Lilian, Williamson, Donald A., Delany, James P., Ravussin, Eric,Wang, Chenxi,. Metabolic and Behavioral Compensations in Response to Caloric Restriction: Implications for the Maintenance of Weight Loss. *PLoS ONE PLoS ONE*. 2009; 4(2):e4377.

34. Sardesai VM. Respiratory Quotient. In: *Introduction to Clinical Nutrition*. Third Edition ed. Boca Raton: Taylor & Francis / CRC Press; 2012, p. 46-47.

35. Scagliusi FB, Ferriolli E, Pfrimer K, Laureano C, Cunha CS, Gualano B, Lourenço BH,Lancha AH Jr,. Characteristics of women who frequently under report their energy intake: a doubly labelled water study. *Eur J Clin Nutr*. 2009; 63(10):1192-9.

36. Schoeller DA vSE. Measurement of energy expenditure in humans by doubly labeled water method. *Journal of applied physiology: respiratory, environmental and exercise physiology*. 1982; 53(4):955-9.

37. Schoeller DA. Measurement of energy expenditure in free-living humans by using doubly labeled water. *J Nutr*. 1988; 118(11):1278-89.

38. Schulz LO, Alger S, Harper I, Wilmore JH,Ravussin E,. Energy expenditure of elite female runners measured by respiratory chamber and doubly labeled water. *Journal of applied physiology (Bethesda, Md.: 1985)*. 1992; 72(1):23-8.

39. Trost S. State of the Art Reviews: Measurement of Physical Activity in Children and Adolescents. *American Journal of Lifestyle Medicine*. 2007; 1(4):299-314.

40. Welk, Gregory J., Corbin, Charles B.,Dale, Darren,. Measurement Issues in the Assessment of Physical Activity in Children. *Research Quarterly for Exercise and Sport Research Quarterly for Exercise and Sport*. 2015; 71(sup2):59-73.

41. Westerterp KR, Brouns F, Saris WH,ten Hoor F,. Comparison of doubly labeled water with respirometry at low- and high-activity levels. *Journal of applied physiology (Bethesda, Md.: 1985)*. 1988; 65(1):53-6.

42. Westerterp KR. Food quotient, respiratory quotient, and energy balance. (Lipids: The Continuing Challenge). *Am J Clin Nutr*. 1993; 57(5).

43. Wickel, Eric E., Welk, Gregory J., Eisenmann,Joey C.,. Concurrent validation of the Bouchard diary with an accelerometry-based monitor. *Med Sci Sports Exerc*. 2006; 38(2):373-9.

44. Yoon Jung Yang, Mi Kyung Kim, Se Hee Hwang, Younjhin Ahn, Jae Eun Shim,Dong Hyun Kim,. Relative validities of 3-day food records and the food frequency questionnaire. *Nutrition Research and Practice*. 2010; 4(2):142-8.

Appendix A: 3-day Food Record

	Ohio State University Sports Nutrition Group

Instructions for Completing the Food Record:

Choose three typical days (2 weekdays and 1 weekend day). Try to eat the way you usually do while you are keeping the food record. Please follow the instructions below as carefully as you can. If you have questions, please e-mail me at buell.7@osu.edu.

1. Record all the food you eat or drink for each day you choose to record. Most people find it helpful to do this as soon after the meal or snack as they can.
2. Write only one food item on a line.
3. Describe the **type of food** eaten as clearly as you can. Use the sample provided as a guide.
   - List ingredients to help describe any unusual casserole or salad.
   - Indicate whether the food is canned, fresh, frozen or diet.
   - List the brand names of foods if you know them.
4. Describe how the food was prepared.
   - Baked, broiled, fried, raw are examples
5. Remember to include all condiments such as pickles, catsup, tartar sauce, salad dressings, gravies and sauces.
6. Be sure to include any snacks such as gum or candy.
7. If you take a vitamin/mineral or other supplement consistently (at least once per week), please return the package label with your food records if it is available. Please list brand name, how many, how often you take them at the top of the first food record.
   - Ex: Centrum plus 1 tablet5 days per week
8. Describe the **amounts** of food you eat and drink as clearly as you can. Use the following examples as a guide.

Food Record

Subject Number in study: ____________________________

Date: _______________________________ Weekday/Weekend

Day/Time	Kind of Food	How Prepared or Brand Name	Amount or Serving Size

Appendix B: Bouchard Physical Activity Record

LABS in Life Runner Study Physical Activity record

Please record the same days as you record for your diet. This is to include two weekdays and one weekend day.

Your subject ID in study:

Date for this page:______________________________

Use the numbers on the left to indicate the average intensity of each 15 minute time block through out your day by writing the intensity number in that time block. Please note that we would like to have the specifics on any activity 6 or above.

Use these intensity numbers for these or similar activities.

1 Sleeping, resting in bed

2 Sitting: eating, listening, writing, watching tv

3 Light activity standing: washing, cooking, brushing

4 Slow walk (less than 24 minute mile), driving, dressing, showering

5 Light manual work: floor sweeping, window washing, painting, waiting on tables, house chores, walk or run at 16-24 minute mile pace

6 Leisure activities and sports in recreational environment such as softball, golf, volleyball, canoeing, bowling, cycling slower than 6.2 mph

7 Manual work at moderate pace such as loading or unloading, snow shoveling, barn work

8 Leisure or sport activities of higher intensity but not yet tough competion such as canoeing 3-5 mph, biking 6.2-9.3 mph, dancing, skiing, tennis, swim, horseback, walking faster than 16 minute mile, floor exercises

9 Intense manual work or competitive sport, carrying heavy loads, running faster than 11 min mile, soccer, basketball, biking faster than 9.3 mph

Blocks of minutes within each hour so that for 1am, 0-15 is 1-1:15, 16-30 is 1:16-1:30 and so on. You should have a number in each box please.

Hour	0-15	16-30	31-45	46-60
midnight				
1 a.m.				
2 a.m.				
3 a.m.				
4 a.m.				
5 a.m.				
6 a.m.				
7 a.m.				
8 a.m.				
9 a.m.				
10 a.m.				
11 a.m.				
noon				
1 p.m.				
2 p.m.				
3 p.m.				
4 p.m.				
5 p.m.				
6 p.m.				
7 p.m.				
8 p.m.				
9 p.m.				
10 p.m.				
11 p.m.				

Please note that we would like to have the specifics on any activity intensity 6 or above. Please provide that right here!